PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 **:**
H02G 15/22, 15/34

A1

(11) International Publication Number: **WO 99/29005**

(43) International Publication Date: 10 June 1999 (10.06.99)

(21) International Application Number: PCT/EP98/07737

(22) International Filing Date: 30 November 1998 (30.11.98)

(30) Priority Data:
9725314.0 28 November 1997 (28.11.97) GB

(71) Applicant *(for all designated States except US)*: ASEA BROWN BOVERI AB [SE/SE]; S–721 78 Västerås (SE).

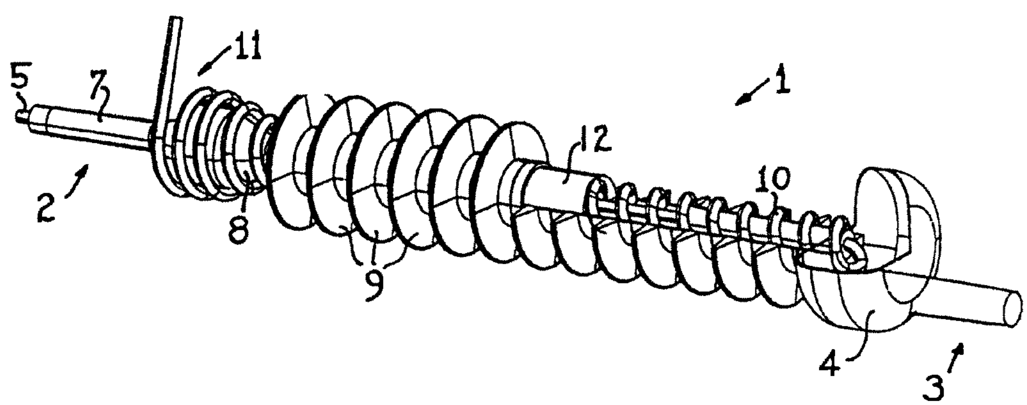
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: LEIJON, Mats [SE/SE]; Hyvlargatan 5, S–723 35 Västerås (SE). SASSE, Christian [DE/SE]; Drottninggatan 4B, S–724 64 Västerås (SE).

(74) Agent: NEWBY, Martin, John; J.Y. & G.W. Johnson, Kingsbourne House, 229–231 High Holborn, London WC1V 7DP (GB).

(81) Designated States: AL, AM, AT, AT (Utility model), AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, EE (Utility model), ES, FI, FI (Utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: A HIGH VOLTAGE POWER CABLE TERMINATION



(57) Abstract

A high voltage power cable termination (1) comprising a current lead (3), a power cable (2) having inner first tube means (5) and outer conducting means, e.g. superconducting means, whose electrically conducting properties improve at low temperatures, arranged around the first tube means and intended in use to be cooled to low temperatures by cryogenic fluid flowing through the first tube means (5), joint means (4) electrically connecting one end of the current lead (3) to the conducting means at one end of the cable at or adjacent one end of the first tube means (5), and second tube means (10) communicating with the first tube means (5) at or adjacent to the joint means (4) for conveying cryogenic fluid to or from the first tube means (5). The first and second tube means (5, 10) are arranged so that, in use, no cryogenic fluid conveyed by the tubes contacts the conducting means or the current lead (3) at the joint means (4). The invention also relates to electrical apparatus, e.g. a high voltage induction device, having such a termination.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

A HIGH VOLTAGE POWER CABLE TERMINATION

Technical Field

This invention relates to a power cable termination for connecting cryogenic high voltage apparatus to a room temperature high voltage line. In particular, but not exclusively, the invention relates to a superconducting power cable termination, such as a termination for a high-temperature (high-T_c) superconducting power cable. The invention also relates to a power cable provided with such a termination and electrical apparatus, such as a power transformer or generator, provided with such a termination. The cable termination is intended to be able to deal with very high operating voltages, e.g., up to 800 kV or more.

Background Art

There are two main functions of a termination for a superconducting power cable. Firstly there is the requirement for converting the high radial electric field in a superconducting cable to an axial electric field after the termination. Secondly, there is the need for the termination to be able to provide the transition between room and cryogenic temperatures. A third requirement is for the termination to be designed for high voltages.

Development work on a termination for a high-T_c superconducting (hereinafter referred to as HTS) cable is described in an article entitled "Development of Termination for the 77KV-Class High T_c Superconducting Power Cable" by T. Shimonosono, T. Masuda and S. Isojima in IEEE Transaction on Power Delivery, Vol. 12, No. 1, January 1997. The main disadvantage of terminations of this known type is that such terminations use liquid nitrogen both as a coolant and as a dielectric. Nitrogen gas bubbles are produced due to the heat inlet and joule heat and these nitrogen bubbles are believed to cause breakdown of the current lead of the termination at increased power levels.

Summary of the Invention

An aim of the present invention is to provide a termination for a cryogenically cooled power cable which overcomes the problems of breakdown associated with known terminations.

A further aim of the present invention is to dispense with the use of liquid nitrogen for electrical insulation of the termination.

According to one aspect of the present invention there is provided a power cable termination comprising:

a current lead;

a power cable having inner first tube means and outer conducting means, whose electrically conducting properties improve at low temperatures, arranged around the first tube means and intended in use to be cooled to low temperatures by cryogenic fluid flowing through the first tube means;

joint means electrically connecting one end of the current lead to the conducting means at one end of the cable at or adjacent one end of said first tube means; and

second tube means communicating with the first tube means at or adjacent to said joint means for conveying cryogenic fluid to or from the first tube means;

the first and second tube means being arranged so that, in use, no cryogenic fluid conveyed by said tubes contacts the conducting means or the current lead at the joint means.

In use of the termination, the cryogenic fluid, e.g. liquid nitrogen, conveyed through the first and second tube

means acts solely as a cooling medium for the conducting means and does not serve as an electrically insulating medium at the joint means. Thus a different medium can be used to provide electrical insulation of the conducting means and the current lead at the joint means.

In most practical applications, the conducting means has superconducting properties. However, the invention is not intended to be limited to conducting means having superconducting properties and is intended to cover any conducting means whose electrical conducting properties significantly improve at low temperatures, e.g. at temperatures below 200 K, preferably below 100 K, e.g. 77 K. In the preferred case of conducting means having superconducting properties, the conducting means may comprise low temperature semiconductors but preferably comprises high-T_c superconducting means. For example the high-T_c superconducting means may comprise silver sheathed BSCCO wire or tape, such as BSCCO-2223 (where the numerals indicate the number of atoms of each element in the $[Bi, Pb]_2$ Sr_2 Ca_2 Cu_3 O_x molecule) or BSCCO-2212. Other examples of known HTS tapes are Ti Ba_2 Ca_2 Cu_3 O_x (TBCCO-1223) and YBa_2Cu_3 O_x (YBCO-123).

The power cable suitably comprises a main portion in which the conducting means is surrounded by electrical insulation, e.g. of solid polymeric material, which, in use of the cable, provides a radial electric field contained within the surrounding electrical insulation, a cable terminating device spaced from said one end of the power cable for converting, in use of the cable, the radial electric field to a substantially axial electric field, and an end portion extending from the cable terminating device to the said one end of the power cable. Conveniently the joint means comprises a high electric potential metallic corona shield to which the conductor lead and the conducting means are connected, e.g by soldering.

Preferably, the electrical insulation surrounding the conducting means comprises an inner layer of semiconducting material which is electrically connected to the conducting means and an intermediate layer of electrically insulating material which surrounds the semiconducting inner layer. The said main portion of the cable also has an outer layer of semiconducting material, which is connected to a controlled electric potential, preferably earth potential, along its length, and which surrounds the said intermediate layer of electrically insulating material. This semiconducting outer layer is not present along the length of the said end portion of the cable, e.g. it is removed to reveal the underlying intermediate layer.

In this specification the term "semiconducting material" means a substance which has a considerably lower conductivity than an electric conductor but which does not have such a low conductivity that it is an electric insulator. Suitably, but not exclusively, the semiconducting material will have a resistivity of from 1 to 10^5 ohm·cm, preferably from 10 to 500 ohm·cm and most preferably from 10 to 100 ohm·cm, typically 20 ohm·cm.

The intermediate layer preferably comprises polymeric material such as, for example, low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), cross-linked materials such as cross-linked polyethylene (XLPE) or rubber insulation such as ethylene propylene rubber (EPR) or silicone rubber. The semiconducting layers are formed of similar polymeric materials but with highly electrically conductive particles, e.g. carbon black or metallic particles, embedded therein. Typical examples of materials for the insulating and semiconducting layers are disclosed in US-A-4,785,138.

Preferably a string of axially arranged annular insulating elements, e.g. of porcelain, glass, polymeric material or rubber material, such as silicone rubber or EPR, surround the said end portion of the cable and extend

between the cable terminating device and the joint means. The annular insulating elements prevent creepage along the outside of the electrical insulation of the end portion of the cable.

In a first design of termination, the superconducting means is arranged around the first tube means but not around the second tube means which is intended to connect the first tube means to cryogenic fluid cooling apparatus. The second tube means may be led directly away from the termination at the joint means. Alternatively, however, the second tube means may be positioned back along or around the outside of the superconducting means so as to extend back from the joint means towards the cable terminating device inside the string of annular insulating elements before being led away from the termination. In this case, the second tube means is preferably wound around the layer of superconducting means surrounding the first tube means. Preferably solid thermal insulation, e.g. of polymeric material having an electric field stress ≤ 0.2 kV/mm, is positioned between the second tube means and the surrounding string of annular insulating elements. The portion of the second tube means leading away from the termination is preferably surrounded by thermal insulation.

According to a second design of termination, the first and second tube means comprise coolant supply and return ducts of a central coolant ducting member of the power cable around which the conducting means, e.g. superconducting means, in tape or wire form, is helically wound. Thus the conducting means is wound around both the first and second tube means. The central coolant ducting member may be divided internally to provide said first and second tube means, the first and second tube means communicating with each other at the said one end of the first tube means. In its simplest form, the internal division of the central coolant ducting member is provided by a diametric partition wall. However to improve thermal efficiency and to ensure bending in all directions, the

ducting member and/or the internal partition wall, may be helically twisted. As an alternative to internally dividing the central coolant ducting member, the latter may be formed as a single tube having a return bend portion at the joint means connecting the first and second tube means which convey the cryogenic fluid in opposite directions in the power cable.

According to other aspects of the present invention there is provided a power cable and electrical apparatus provided with a termination according to said one aspect of the present invention.

Brief Description of the Drawings

Embodiments of the invention will now be described, by way of example only, with particular reference to the accompanying drawings, in which:

Figure 1 is a schematic, partially cut away, perspective view of one embodiment of a power cable termination according to the invention;

Figure 2 is a schematic, partially cut away, perspective view of another embodiment of a power cable termination according to the invention;

Figure 3 is a schematic, partially cut away, view of a yet further embodiment of a power cable termination according to the invention; and

Figure 4 is a detail on an enlarged scale of a part of the termination shown in Figure 3.

Figure 1 shows a superconducting high voltage power cable termination, generally designated by the reference numeral 1, for terminating a high-T_c superconducting cable (or HTS cable) 2. In addition to the cable 2, the termination 1 comprises a current lead 3, e.g. a high

voltage metal connection to an overhead line (not shown), and a corona shield 4 in the form of a metallic toroid to which the HTS cable 2 and current lead 3 are electrically connected, e.g. by soldering. The corona shield 4 has internal and/or external thermal insulation (not shown).

The HTS cable 2 suitably comprises a centrally positioned support or first tube 5 on which superconducting wire or tape (not shown), e.g. silver-sheathed BSCCO wire or tape, is helically wound. Electrical insulation 7 is provided, e.g. extruded, around the helically wound tape along a main part of the cable 2 up to a cable terminating cone or device 8. The electrical insulation 7 suitably comprises inner and outer layers of semiconducting material and an intermediate layer of electrically insulating material positioned between the layers of semiconducting material. Suitably, but not exclusively, the semiconducting material will have a volume resistivity of from 1 to 10^5 ohm·cm, preferably from 10 to 500 ohm·cm and most preferably from 10 to 100 ohm·cm, e.g. 20 ohm·cm. The insulating layer conveniently comprises solid polymeric material, examples of which are low and high density polyethylene (LDPE and HDPE), polypropylene (PP), polybutylene (PB), polymethylpentene (PMP), ethylene (ethyl) acrylate copolymer, cross-linked materials such as cross-linked polyethylene (XLPE) or rubber insulation such as ethylene propylene rubber (EPR) or silicone rubber. The semiconducting layers are formed of similar polymeric materials but with highly electrically conductive particles, e.g. carbon black or carbon soot, embedded therein. Typical examples of materials for the insulating and semiconducting layers are disclosed in US-A-4,785,138.

The semiconducting inner layer of the electrical insulation is electrically connected with the superconducting wire or tape. The semiconducting outer layer is connected to a controlled electric potential, preferably earth potential, so that the electric field generated by the HTS power cable 2 is radially contained

within the electrical insulation 7. Conveniently the semiconducting outer layer is electrically to the controlled electric potential at spaced apart regions along its length.

The electrical insulation 7 should conveniently be such that the electric field stress is less than or equal to 0.2 kV/mm in any gaseous space inside or outside the termination. This will ensure that no electrical discharges occur around the termination.

At the cable terminating device 8, the outer layer of semiconducting material is stripped from the insulation 7 to reveal the underlying electrically insulating material along an end portion of the cable 2 between the cable terminating device 8 and the corona shield 4. The electrical insulation around the superconducting tape or wire supported on the first tube 5 along said end portion of the cable 2 is provided firstly by the inner layer of semiconducting material and the surrounding intermediate layer of electrically insulating material and secondly by a plurality of annular electrically insulating elements 9, e.g. of porcelain, arranged in a string for preventing creepage.

At the end of the cable 2, the superconducting wire or tape wound around the first tube 5 is electrically connected to the corona shield 4 and the current lead 3. Also a second tube 10 of electrically non-conductive material is connected to, so as to communicate internally with, the first tube 5. The first and second tubes may be integrally formed as a single tube or may be two separate, joined together, tubes. However, the second tube 10 has no superconducting wire or tape wound therearound. The second tube 10 is wound back along the end portion of the cable 2 between the layer of electrically insulating material and the string of insulating elements 9. The second tube 10 is wound around the terminating device 8 and exits the termination at 11 for connection to a cooling machine (not shown) for cooling cryogenic coolant fluid conveyed by the tubes 5 and 10. The exit point 11 is thus at a position

where there is no electric field surrounding the cable 2. In other embodiments (not shown), the exit point 11 could be spaced a short distance from the device 8 between the device 8 and the corona shield 4 so that the point 11 would be at a relatively low electric potential compared with the high electric potential at the corona shield 4. The tube 10 is surrounded by thermal insulation 12 inwardly of the insulating elements 9 and by further thermal insulation (not shown) between the termination 1 and the cooling machine. The thermal insulation 12 is shown cut away in Figure 1, but would in practice completely surround the coiled second tube 10 between the corona shield 4 and the exit point 11.

The exterior of the electrical insulation 7 and the cable terminating device 8 are at a controlled electric potential, preferably earth potential, which contrasts with the very high electrical potential of the corona shield 4. The string of electrical insulators 9 prevent creepage, i.e. prevent leakage of electricity along the surrounded surface of the cable insulation between the corona shield 4 and the cable terminating device 8. At the cable terminating cone or device 8, the radial electric field around the superconducting cable 2 is converted to an axial field.

The cable termination 20 shown in Figure 2 is similar in many respects to the termination 1 shown in Figure 1 and where possible the same reference numerals have been used in the two figures to identify the same or similar parts. The main difference between the two terminations 1 and 20 is that the second tube 10 of termination 20 is not wound back around the first tube 5 but, instead, leaves the termination at the corona shield 4. As shown, the second tube 10 projects through the toroidal corona shield before being connected to a cooling machine (not shown). The second tube 10 is surrounded by thermally insulating material 21, e.g. void-free, solid plastics material, between the corona shield 4 and the cooling machine (not shown) and also a string of electrical insulators 22. Thermal insulation 12 is also arranged between the cable terminating device and

the corona shield 4 in the annular space between the electrically insulating material surrounding the superconducting wire or tape and the string of electrically insulating elements 9.

Figures 3 and 4 show a further embodiment of a superconducting cable termination according to the invention and designated by the reference numeral 30. The cable termination 30 is similar in many respects to the terminations 1 and 20 and where possible the same reference numerals have been used to identify the same or similar parts. The main difference between the termination 30 and the two terminations 1 and 20 is that, in the termination 30, the HTS cable 2 is provided with two centrally positioned inner tube portions 31 and 32 about which the superconducting wire or tape is wound. These tube portions 31 and 32 are joined together by a return bend tube portion 33 (see Figure 4) at the end of the cable where the superconducting tape or wire is joined, e.g. soldered to the corona shield 4. The tube portion 33 may be a separate tubular connector connected to the tube portions 31 and 32. Alternatively the tube portions 31-33 may be portions of a single, integral tube 34 which is merely bent at tube portion 33. In other respects the termination design is similar to the termination 1 shown in Figure 1.

Instead of winding the superconducting wire or tape around the two inner tube portions 31 and 32, a central tubular support may comprise a single tube (not shown) divided up to a short distance from the tube end by an internal partition to provide supply and return ducts for the cryogenic fluid which communicate with each other at the tube end. The cooling efficiency can be slightly improved by constructing the support tube and/or its inner partition as a helix so that the surrounding superconducting wire or tape is cooled along a helical path. Alternatively the support tube could be designed as a pair of concentric tubes, the inner tube serving as a return duct for the cryogenic fluid, the superconducting wire or tape being

wound on the outside of the outer tube and the annular gap between the inner and outer tubes providing a supply duct for the cryogenic fluid.

In each of the terminations 1, 20 and 30 described above, the thermal and electrical insulation of the termination in question are separated. In particular the cryogenic coolant fluid for cooling the superconducting means to superconducting temperatures serves solely as a cooling medium and is not used in addition for electrically insulating purposes. Thus the cryogenic fluid does not serve as a dielectric unlike in known superconducting power cable terminations. In this manner known problems associated with nitrogen gas bubbles being generated in the surrounding electric insulation are avoided.

The HTS cable described may be of any convenient design and is not limited to the specific cryogenic dielectric design described in the specific embodiments. Thus, for example, the HTS cable may be of a so-called room-temperature dielectric design with the superconducting means externally thermally insulated from electric insulation by thermal superinsulation contained between corrugated metal tubes.

Although the present invention is primarily directed to a power cable termination for teminating a power cable with conducting means having superconducting properties which are cooled in use to superconducting temperatures, e.g. by liquid nitrogen at 77 K, the invention is also intended to embrace conducting means which have improved electrical conductivity at a low operating temperature, up to, but preferably no more than, 200 K, but which may not possess superconducting properties at least at the intended low operating temperature. At these higher cryogenic temperatures, liquid carbon dioxide can be used for cooling the conductor means.

The power cable termination is intended for use as a termination in electrical apparatus, e.g. high boltage induction devices such as power transformers, generators and energy storage devices, such as SMES devices.

The electrical insulation used in a power cable termination, power cable or electrical apparatus according to the invention is intended to be able to handle very high voltages and the consequent electric and thermal loads which may arise at these voltages. By way of example, a power termination according to the invention can be used in terminations for power transformers having rated powers from a few hundred kVA up to more than 1000 MVA and with rated voltages ranging from 3-4 kV up to very high transmission voltages of 400-800 kV. At high operating voltages, partial discharges, or PD, constitute a serious problem for known insulation systems. If cavities or pores are present in the insulation, internal corona discharge may arise whereby the insulating material is gradually degraded eventually leading to breakdown of the insulation. The electric load on the electrical insulation of the power cable of a termination according to the present invention is reduced by ensuring that the inner layer of the insulation is at substantially the same electric potential as the inner conducting means and the outer layer of the insulation is at a controlled, e.g. earth, potential. Thus the electric field in the intermediate layer of insulating material between the inner and outer layers is distributed substantially uniformly over the thickness of the intermediate layer. Furthermore, by having materials with similar thermal properties and with few defects in the layers of the insulating material, the possibility of PD is reduced at a given operating voltages. The power cable of the termination can thus be designed to withstand very high operating voltages, typically up to 800 kV or higher.

Although it is preferred that the electrical insulation 7 should be extruded in position, it is possible to build up an electrical insulation system from tightly

wound, overlapping layers of film or sheet-like material. Both the semiconducting layers and the electrically insulating layer can be formed in this manner. An insulation system can be made of an all-synthetic film with inner and outer semiconducting layers or portions made of polymeric thin film of, for example, PP, PET, LDPE or HDPE with embedded conducting particles, such as carbon black or metallic particles and with an insulating layer or portion between the semiconducting layers or portions.

For the lapped concept a sufficiently thin film will have butt gaps smaller than the so-called Paschen minima, thus rendering liquid impregnation unnecessary. A dry, wound multilayer thin film insulation has also good thermal properties and can be combined with a superconducting pipe as an electric conductor and have coolant, such as liquid nitrogen, pumped through the pipe.

Another example of an electrical insulation system is similar to a conventional cellulose based cable, where a thin cellulose based or synthetic paper or non-woven material is lap wound around a conductor. In this case the semiconducting layers, on either side of an insulating layer, can be made of cellulose paper or non-woven material made from fibres of insulating material and with conducting particles embedded. The insulating layer can be made from the same base material or another material can be used.

Another example of an insulation system is obtained by combining film and fibrous insulating material, either as a laminate or as co-lapped. An example of this insulation system is the commercially available so-called paper polypropylene laminate, PPLP, but several other combinations of film and fibrous parts are possible. In these systems various impregnations such as mineral oil or liquid nitrogen can be used.

CLAIMS

1. A high voltage power cable termination (1) comprising:

a current lead (3);

a power cable (2) having inner first tube means (5) and outer conducting means, whose electrically conducting properties improve at low temperatures, arranged around the first tube means and intended in use to be cooled to low temperatures by cryogenic fluid flowing through the first tube means (5);

joint means (4) electrically connecting one end of the current lead (3) to the conducting means at one end of the cable at or adjacent one end of said first tube means (5); and

second tube means (10) communicating with the first tube means (5) at or adjacent to said joint means (4) for conveying cryogenic fluid to or from the first tube means (5);

the first and second tube means (5,10) being arranged so that, in use, no cryogenic fluid conveyed by said tubes contacts the conducting means or the current lead (3) at the joint means (4).

2. A termination according to claim 1, characterised in that the electrically conducting properties of the conducting means improve at temperatures below an operating temperature no greater than 200 K, preferably no greater than 100 K, e.g. 77 K, the cryogenic fluid, in use of the termination, cooling the conducting means to said operating temperature.

3. A termination according to claim 1 or 2, characterised in that the conducting means has

superconducting properties and that, in use of the termination, the conducting means is cooled to superconducting temperatures by said cryogenic fluid.

4. A termination according to claim 3, characterised in that the conducting means comprises high-T_c superconducting means.

5. A termination according to claim 4, characterised in that the high-T_c superconducting means comprises silver sheathed BSCCO wire or tape.

6. A termination according to any one of the preceding claims, characterised in that the power cable (2) comprises a main portion in which the conducting means is surrounded by electrical insulation (7) which, in use of the cable, provides a radial electric field contained within the surrounding electrical insulation, a cable terminating device (8) spaced from said one end of the power cable for converting, in use of the cable, the radial electric field to a substantially axial electric field, and an end portion extending from the cable terminating device (8) to the said one end of the power cable.

7. A termination according to claim 6, characterised in that the said joint means comprises a high electric potential metallic corona shield (4) to which the conductor lead (3) and the conducting means are electrically connected, e.g. by soldering.

8. A termination according to claim 6 or 7, characterised in that the said electrical insulation (7) comprises an inner layer of semiconducting material electrically connected to the conducting means, an outer layer of semiconducting material connected to a controlled electric potential, e.g. earth potential, along its length, and an intermediate layer of electrically insulating material between said semiconducting inner and outer layers.

9. A termination according to claim 8, characterised in that the said inner layer of semiconducting material and the said intermediate layer of electrically insulating material also surround the conducting means along the said end portion of the cable, but the said outer layer of semiconducting material does not extend along the said end portion.

10. A termination according to claim 8 or 9, characterised in that the semiconducting material has a resistivity of from 1 to 10^5 ohm·cm, preferably from 10 to 500 ohm·cm and most preferably from 10 to 100 ohm·cm.

11. A termination according to claim 8, 9 or 10, characterised in that the intermediate layer comprises polymeric material.

12. A termination according to any one of claims 8 to 11, characterised in that the or each semiconducting layer is formed of polymeric material with highly electrically conductive particles, e.g. carbon black or metallic particles, embedded therein.

13. A termination according to claim 11 or 12, characterised in that the said polymeric material comprises low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), cross-linked materials, for example cross-linked polyethylene (XLPE), or rubber insulation such as ethylene propylene rubber (EPR) or silicone rubber.

14. A termination according to any one of claims 6 to 13, characterised in that a string of axially arranged annular insulating elements (9), e.g. of porcelain, glass, polymeric material, or rubber, surround the said end portion of the cable and extend between the cable terminating device (8) and the joint means (4).

15. A termination according to claim 14, characterised in that thermal insulation (12) is provided along the said end portion of the cable radially inwardly of the surrounding annular insulating elements (9).

16. A termination according to any one of claims 6 to 15, characterised in that the said electrical insulation is designed for high voltage, suitably in excess of 10 kV, in particular in excess of 36 kV, and preferably more than 72.5 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher.

17. A termination according to any one of claims 6 to 16, characterised in that the said electrical insulation is designed for a power range in excess of 0.5 MVA, preferably in excess of 30 MVA and up to 1000 MVA.

18. A termination according to any one of the preceding claims, characterised in that the second tube means (10) is led directly away from the termination at the joint means (4).

19. A termination according to claim 14 or 15 or either of claims 16 or 17 when dependent on claim 14 or 15, characterised in that the second tube means (10) extends back from the joint means (4) and inside the string of annular insulating elements (9) before being led away (at 11) from the termination.

20. A termination according to claim 19, characterised in that the second tube means (10) is wound around the first tube means (5).

21. A termination according to claim 19 or 20, characterised in that thermal insulation (12) is arranged between the second tube means (10) and the surrounding string of annular insulating elements (9).

22. A termination according to any one of claims 18 to 20, characterised in that the second tube means (10) after being led away from the termination is surrounded by thermal insulation (21).

23. A termination according to claim 22, characterised in that the second tube means (10) after being led away from the termination is surrounded by a string of annular insulating elements (22).

24. A termination (30) according to any one of claims 1 to 17, characterised in that the first and second tube means comprise coolant supply and return ducts (31, 32) of a central coolant ducting member (34) of the power cable (2) around which the conducting means, in tape or wire form, is helically wound.

25. A termination according to claim 24, characterised in that the central coolant ducting member is divided internally to provide said first and second tube means, the first and second tube means communicating with each other at the said one end of the first tube means.

26. A termination according to claim 25, characterised in that the internal division of the central coolant ducting member is provided by a diametric partition wall.

27. A termination according to claim 25, characterised in that the ducting member and/or the internal partition wall, are helically twisted.

28. A termination according to claim 24, characterised in that the central coolant ducting member is formed as a single tube (34) with a return bend portion (33) at the joint means (36) connecting said first and second tube means (31, 32) which are intended to convey the cryogenic fluid in opposite directions internally within the power cable (2).

29. A power cable provided with a termination according to any one of the preceding claims.

30. High voltage electrical apparatus having a termination according to any one of claims 1 to 28.

FIG. 1

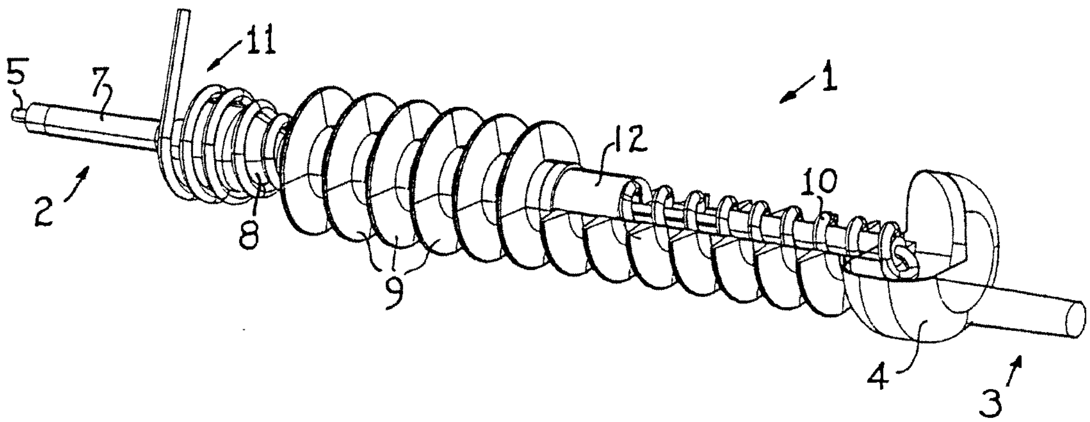


FIG. 2

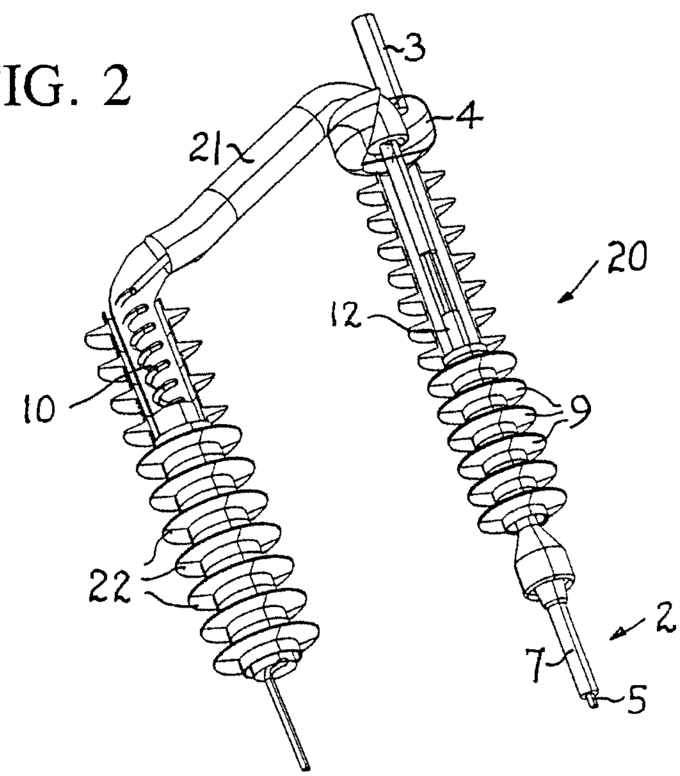


FIG. 4

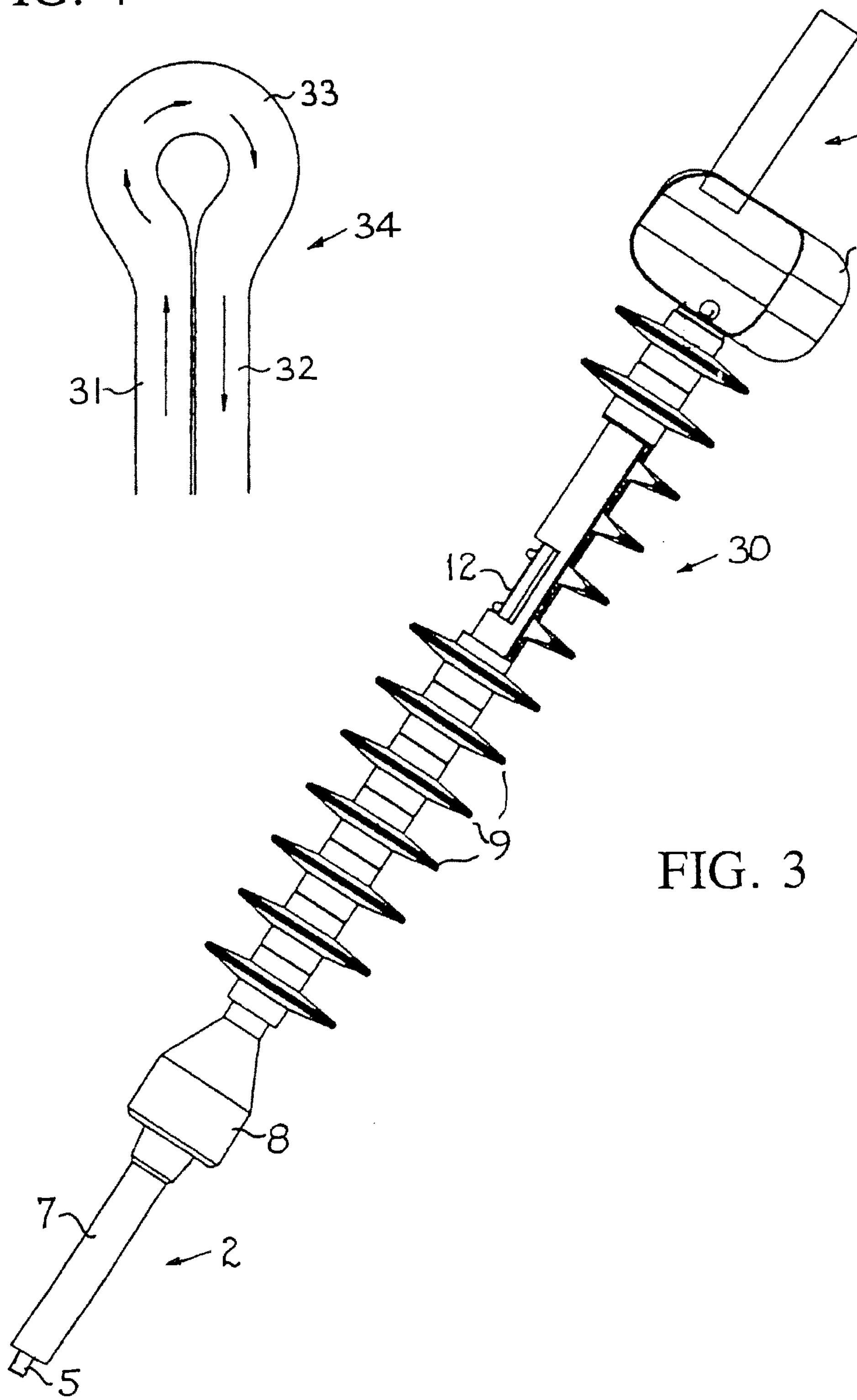


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP 98/07737

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02G 15/22, H02G 15/34
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3716652 A (G.E. LUSK ET AL), 13 February 1973 (13.02.73), column 3, line 51 - line 65; column 4, line 14 - line 63; column 7, line 16 - line 62, figures 1-4 --	1-4,18,24, 25,29,30
X	US 3902000 A (E.B. FORSYTH ET AL), 26 August 1975 (26.08.75), column 1, line 38 - column 2, line 8; column 4, line 53 - column 5, line 36, figures 1-4 --	1-4,18,24, 25,29,30
A	EP 0780926 A1 (PIRELLI CAVI S.P.A.), 25 June 1997 (25.06.97), page 4, line 23 - line 41; page 5, line 23 - line 58, figures 1-4 --	1-30

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" erlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 March 1999	21. 04. 99

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ingemar Hedlund

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP 98/07737

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3758699 A (G.E. LUSK ET AL), 11 Sept 1973 (11.09.73), column 5, line 8 - line 44; column 7, line 66 - column 8, line 14, figures 1-8	1-30

--

SA 220520

INTERNATIONAL SEARCH REPORT

Information on patent family members

02/03/99

International application No.
PCT/EP 98/07737

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 3716652 A	13/02/73	CA 968425 A	27/05/75
		DE 2260746 A	31/10/73
		JP 1041133 C	23/04/81
		JP 49020681 A	23/02/74
		JP 55032101 B	22/08/80
US 3902000 A	26/08/75	NONE	
EP 0780926 A1	25/06/97	AU 7427196 A	26/06/97
		BR 9604741 A	23/06/98
		CA 2192533 A	22/06/97
		IT 1281651 B	20/02/98
		IT MI952723 A	23/06/97
		JP 9190847 A	22/07/97
		NZ 299899 A	25/03/98
US 3758699 A	11/09/73	CA 993063 A	13/07/76
		DE 2312981 A	20/09/73
		JP 1131408 C	17/01/83
		JP 49002081 A	09/01/74
		JP 57000727 B	07/01/82